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# Comparing microplastics contaminants in (dry and raining) seasons for Ox-Bow Lake in Yenagoa, Nigeria

Babalola Aisosa Oni[a,*], Augustine O. Ayeni[a], Oluranti Agboola[a], Tomiwa Oguntade[b], Oyinlola Obanla[a]

[a] Department of Chemical Engineering, Covenant University, KM 10 Idiroko road, P.M.B 1023, Ota, Ogun state, Nigeria
[b] Department of Petroleum Engineering, Covenant University, KM 10 Idiroko road, P.M.B 1023, Ota, Ogun state, Nigeria

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ABSTRACT

The occurrence and distribution of microplastics (MPs) for two seasons (dry and raining) were investigated based on 10 sections of OX- Bow Lake Yenagoa, Nigeria for surface water and sediments. MPs were abundant in colour and dominated by fibrous items. For dry season, Polyethylene terephthalate (PET) and Plasticised polyvinyl chloride (Plasticised PVC) were the predominant MPs; they both account for 72.63% and 10.9% of surface water and sediment samples. The raining season accounted for Plasticised (PVC) 81.5% and low-density polyethylene 4.2% respectively. The raining and dry seasons MPs were characterise by μ-FTIR. Beads and pellets were most common MP shapes in both water and sediment samples for the two seasons. The results showed that there is high presence of MPs in OX –Bow Lake.

## 1. Introduction

Plastics and their production rates has increased over the years. As of 2018, about 380 million tonnes of plastic is produced worldwide each year. The fast growth of plastics production and use is mainly due to the exceptional properties of the material (Koelmans et al., 2013). Plastics have a high strength-to-weight ratio, which can be shape into any forms; they are impermeable to water and resistant to physical and chemical degradation. Plastics are a diverse set of materials with specific chemical and physical properties (Hidalgoruz et al., 2012). Due to its diverse nature and vastness, they are used in different categories, which include polyvinyl chloride (PVC), high-density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), acrylic (PPA) fibres, polyurethane (PUR), polyester, low-density polyethylene (LDPE), polyamide and polyethylene terephthalate (PET) (Ziajahromi et al., 2017). Plastics packaging is the largest application by weight, they can be use in transport of materials, textile and construction sectors. Some polymers of plastic are used mainly in a single application, for example, polyethylene in packaging, while others have wide range of application, for example, a polypropylene (Vollertsen and Hansen, 2017).

Consequently, millions of tonnes of plastics enter oceans and landfills annually (Eerkes-Medrano et al., 2015). Substantial amounts of plastics culminate in waterways, predominantly in the aquatic environment. Research shows that 5.0–13.7 million tons of plastic wastes enters the ocean in 2016 (Hintersteiner et al., 2015). Plastics entering marine environments have a wide size distribution, ranging from micrometres to meters. MPs are very small pieces of plastic that pollute the environment. MPs are not a specific kind of plastic, but rather, they are plastic debris that is <5 mm in size. So far, MPs occurrence was typically determined in marine water, sediments or biota samples (Abrahams et al., 2007).

Pollution of marine environments by MPs were originated from the release of primary factory-made particles employed in various industrial and household activities, and the degradation of larger plastics items into micro-sized fragments (Harrison et al., 2012). Many MPs in consumer products for example polypropylene, high/low density polyethylene etc. are less dense than water, and they have shown to be highly vulnerable to micro particle generation through breakdown (Cable et al., 2017). Research have demonstrated that microplastic occurrence can cause health and environmental issues. MPs are most times mistaken for food, leading to organ blockage of aquatic organisms, light is hindered by MPs suspends in the ocean because of low density, this may decrease the efficient use of light for marine organisms; microplastics are carriers for persistent organic pollutants (POPs) due to its large specific surface area and strong hydrophobicity (McCormick et al., 2014; Xiong et al., 2018). Examples of (POPs), include polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), etc., these have the capacity to adhere to MPs, because

* Corresponding author.
*E-mail address:* babalola.oni@covenantuniversity.edu.ng (B.A. Oni).

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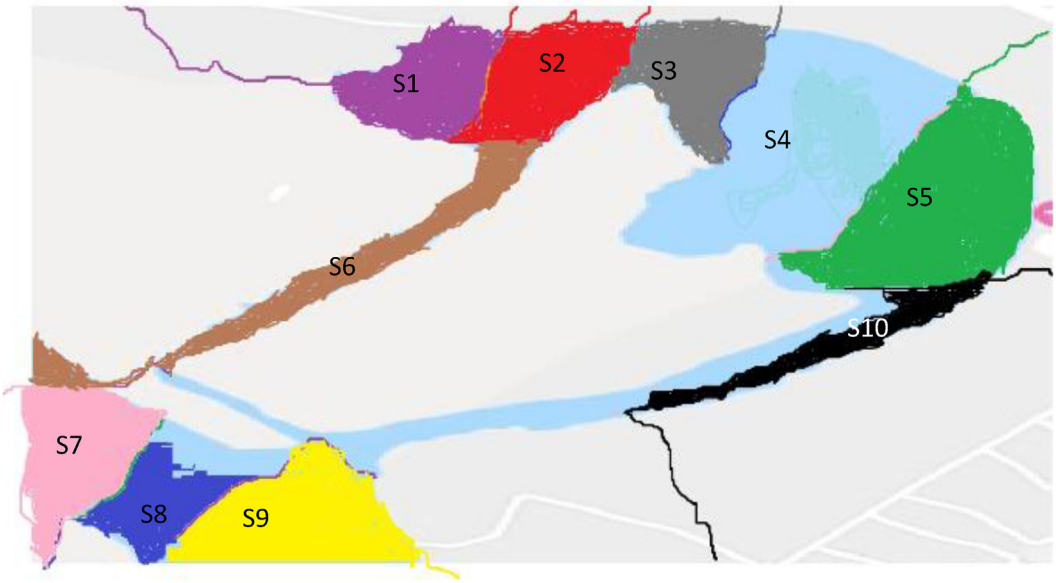


**Fig. 1.** Study area of Ox-bow Lake in Yenagoa, Nigeria; Source: Ministry of Environment, Bayelsa State, Nigeria. S1 (Amasoma), S2 (Opokuma), S3 (Epie), S4 (Tombia), S5 (Sagbama) S6 (Brass) S7 (Ovom) S8 (Ogbia), S9 (Nembe) and S10 (Swali).

to their hydrophobicity. With microplastics, being identified in freshwaters for example rivers, streams, lakes; less concern have been paid to their corresponding behaviours, especially to human health due to its effect on drinking water treatment to some extent. Environmental impacts of microplastics have raised emergent concern to the public. (Ballent et al., 2016; Rodrigues et al., 2018).

Ghosal et al. (2018) determined the microplastics concentrations of the influent and secondary effluent water of two wastewater treatment plants in Turkey. Their results displayed that the influent of the wastewater treatment contained 1–6.5 million particles per day, while the effluent contained 220,000–1.5 million particles per day. The removal rate of microplastics was not too high as it was found to be between 73% and 79%.

Zhao et al. (2015) have reported MPs occurrences in terrestrial, estuarine, coastal marine and freshwater environments. Hernandez et al. (2017) showed that about 1.09–2.33 million tons of plastic fragments from worldwide rivers discharged into the oceans annually. Researchers also demonstrated that about 210.2 trillion microbeads emitted annually into marine environments originated from wastewater treatment plants (Redondo-Hasselerharm et al., 2018). The ever presence nature alongside with the observed intensity of microplastic contaminant urges research in the fluvial environments (Carr et al., 2016).

MPs are of two types, Primary and Secondary. The former talk about the plastics manufactured solely in small size, e.g. microbeads used in personal care products and media used in air-blasting technology (Fok and Cheung, 2015). The latter is produced from fragmentation of large plastic debris as a result of photo-degradation, mechanical weathering, chemical and biological processes in environments (Ziajahromi et al., 2017; Mason et al., 2018).

MPs are distributed on the water surface, which depends on its properties, for example, size, density, shape, adsorption of chemicals and biofouling; waves, water density, currents and wind are based on environmental condition (Claessens et al., 2013). Therefore, the quality and quantity of MPs recovered are dependent on depth and sampling location. Processing and sampling methods are alike especially in salt and freshwater samples, enabling a prospective standardization of methods. Although, they may not be similar in the distribution of MPs in each system, caused by environmental factor, for example, density and hydrodynamic profile. Density difference of salt and freshwater 1.03 g $cm^3$ and 1.00 g $cm^3$, may result to distinctive distribution of MPs in the water column (Su et al., 2016).

MPs distribution on sediments is irregular, largely caused by their characteristics and environmental factors, for example, winds and ocean currents. This is solely depends on the sampling area and depth; however some section may have greater concentrations of MPs. For example, sediments collection in tide-line, large build-up area for MPs, may result in overestimation (Cole, 2016; Carr et al., 2016). Collection of MPs on beaches consist of direct sampling with forceps, sieving and collection of sediments. Samples collected from seabed requires a vessel and specialised equipment that is lowered to the seabed where sample is collected, for example the use of grab sampler and box corer). An accurate approximation of the concentration of MP in sediment samples requires the definition of sampling depth. (Hernandez et al., 2017).

Yenagoa is surrounded by water, which is about 65% land and 35% water and it is very close to the Atlantic Ocean, south – south Nigeria. Nigeria has two seasons, which comprise of raining and dry season. The raining season occurs between April to October every year, while the dry season occurs between Novembers to March every year.

Ox – Bow Lake is few kilometre close to the Atlantic Ocean. It is the largest Nigeria Lake and watershed in Nigeria at over 382,000 $km^2$, in which nearly 1,300,000 people live and work. Yenagoa city is reported to produce 2.03 million tonnes of solid wastes and 0.27 billion tons of wastewater in 2018 (Ministry of Environment, Bayelsa State, Nigeria, 2018). However, these wastes were not rightly manage in Yenagoa; MPs could be discharge into the lake, through sewage, effluents from industries, and atmospheric deposition. According to the Ministry of Environment, Bayelsa State, Nigeria, 6000 tons of plastic wastes were discharged into the lake annually. The lake is very important as microplastic sources, transport and accumulation, making it hotspots of microplastic pollution. Thus, the knowledge gap called for the needs of this study, in which the abundance and spatial distribution of microplastics were, investigated in surface water and sediments of Ox – Bow Lake. The probable source of microplastics and its dominant factors were also addressed. Hence, the aim of this article is to compare the level of MPs contaminants in (dry and raining) seasons for Ox- Bow Lake in Yenagoa, Nigeria in terms of surface water and sediments. Fig. 1 shows the study area of Ox-bow Lake in Yenagoa, Nigeria, the map of Yenagoa is displayed in S1, where Ox- Bow Lake is located. S2 illustrates the map of Nigeria and Africa. S3 shows the pictorial representation of Ox-bow Lake in Yenagoa, Nigeria. Table 1 explains the sample collection in water and sediments.

**Table 1**
Sample collection in water and sediments.

| Sample | Type | Merits | Demerits | Reference |
|---|---|---|---|---|
| Water | Filtration or sieving | Known volume of water; Allow choice of mesh size; Easy to collect sample | Difficulty and time consuming; Sample low volumes; requires manual operation; transportation of water to the lab. | Vollertsen and Hansen (2017) |
| | Sieving | Easy to collect ample; specialised equipment may not be required, may not require boat. | Sample medium volumes; Difficulty and time consuming; requires manual operation. | Su et al., 2016; Ballent et al. (2016) |
| Sediment | Seabed collection (gravity core, grab sampler, box corer) | Allows replicates; easy to use. | The equipment is costly; boat is required; Sample may disturb Sediment surface. Variation with Sample depth and area | Rodrigues et al. (2018); Abrahams et al. (2007). |

## 2. Materials and method

The OX- Bow lake (34° 38′−32° 50′ N, 120° 62′− 114° 46′E) is located in Yenagoa, Bayelsa state with a water surface area of over 23,220 $km^2$. Towns round the lake are small in scale and less developed in industry, majorly dominated by farming and fishing. The first step in MP sampling methods is the collection of sediment and water samples. MPs distribution is influenced by geographical, meteorological and temporal factors that may compromise reproducibility of the results (Eerkes-Medrano et al., 2015). Alternatively, methodology and quantity of sampled materials may affect the true representations of result. Surface water samples and sediments were collected at 10 locations, representing 10 sections of the lake (which are Amasoma, Opokuma, Epie, Tombia, Sagbama, Brass, Ovom, Ogbia, Nembe and Swali) between December 4, 2018 for dry season and June 15th, 2019 for raining season respectively of which all sediments were used for the analysis. Specifically, according to the dwellers, the lake is divided into 10 sections, namely: Amasoma, Opokuma, Epie, Tombia, Sagbama, Brass, Ovom, Ogbia, Nembe and Swali. Sampling tools were all cleaned prior to the next sampling to avoid contamination. Fig. S3 shows the description of each sampling site. Concisely, 50 L of bulk surface water samples were collected from each site of the lake, whereby the water was sampled by means of a clean Teflon pump, which passes through a stainless steel of mesh. The Materials on the mesh were rinsed into a clean beaker using distilled water. Immediately, the sediments were collected with a grab sampler from 10 sections of the site. In addition, a total of 2 kg surface sediments on the top 5 cm were collected randomly from the sampler and put into an aluminium foil bag. Two replicates were taken at each sampling point for water and sediment samples. All samples were preserved at −3 °C in the laboratory, awaiting further analysis and labelled for each season.

### 2.1. Sample analysis

Following (Su et al., 2016) and (Di and Wang, 2018) on sample analysis, after digestion of organic substances on the surface of the samples with $H_2O_2$ (30%, v/v) for 12 h, each sample of surface water were filtered through a 0.40 μm glass microfiber filter paper (GF/F, 45 mm Ø, Whatman). The filter paper was immediately transferred to a Petri dish and allowed to dry prior to microscopic examination. Samples of sediment were extracted using a two-step extraction method, stated by (Di and Wang, 2018). (MPs are separated from water and sediment in for quantification and characterization. Samples may be subjected to two separation processes: (1) a reduction step, which allows reducing sample volume, for example, using nets during collection or bulk collection followed by sieving; (2) a separation step, through filtration and/or density separation. Density separation, with the use of sodium chloride is endorsed by both (Marine strategy framework directive) (MSFD) technical subgroup (2013) and National oceanic and atmospheric administration (NOAA). 600 g of wet sediments were placed inside a 2500 mL beaker with the addition of saturated solution of 1000 mL NaCl to ensure homogeneity. The supernatant was gathered and filtered at 48 μm, into a separate beaker. This was done thrice for other sample. Furthermore, the microplastic was extracted with sodium iodide solution.

Sediments that was remaining were transferred to a conical flask, with the addition of 65% NaI solution. After rigorous shaken and stratified, the clear supernatant extracted was treated the same as the last step (Simon et al., 2018; Cole et al., 2014). This process was carried out thrice. Lastly, the water samples were filtered through a membrane of 5 μm to collect all of the suspected microplastics. The filter was preserved for further examination. During the experiment, all equipment were thoroughly cleaned and sealed with foil when not in use, gloves and a pure cotton laboratory coat were worn to avoid contamination. After extraction, residue on the filter were seen with a dissecting microscope with an ocular micrometre (M165 FC, Leica,

Germany). Suspected MPs were recorded (colour, size, type and shape) in accordance with their physical appearances and the grouping standards obtained from previous study (Yang et al., 2015; Bayo et al., 2016).

Wet sediments kept in an aluminium bag were moved into an uncontaminated aluminium disk, dried at 70 °C between 2 and 3 days. During drying for that period, the disks were enclosed with aluminium foil to reduce contamination from air. The sediment which was dried were gently crushed to disaggregate the cake. Items like sand, rocks, large plastic debris and wood were removed. For every sediment sample crushed, a record of 100 g sediments were sub-sampled, weighed and retained into a flask, in which 1 L saturated sodium chloride solution was added. The supernatant was following previous study (Corcoran et al., 2015; Dris et al., 2015). The process were repeated three times for maximum amount of microplastics from sediments. The supernatant was filtered under vacuum condition through a-20 μm membrane filter. Successively, 400 mL of 20% KOH was added, shaken at 70 °C and 100 rpm for 20 h for digestion. After digestion, 800 mL of saturated sodium chloride solution was added and then filtered over a clean 5 μm membrane filter using a vacuum system. The final filter was placed into a clean petri dish and covered for further analysis. Hence, suspected particles were arbitrarily chosen from all of the filters and measured by μ-Raman spectroscopy (Thermos Fisher Sci. DXRR2, 530 nm laser, Raman shift 50–3500 $cm^{-1}$). The particles were compared with database of the equipment and polymer types identified. The purpose of Raman spectroscopy is for detection of materials in water environments and might be able to make up for the deficiencies of the other detection technologies. Raman spectroscopy has developed into an excellent and effective tool for detection of pollutants in a water environment due to its high precision and detection efficiency, non-destructive sampling capability and minimal sample preparation. With the use of optical fibres, it will enable the equipment to locate far away materials to allow remote and on-line detection of specific materials in water, it also provide micrometre-scale analysis with spectral resolutions of up to 1 $cm.^{-1}$

### 2.2. Flotation and elutriation

Variations in density is vital in separating plastics from sediment, by mixing the sediment with saturated sodium iodide. Sodium Iodide (1.6 g $cm^3$) separates heavier polymers with good recovery rates (99 percent) and tight error bars. In addition, separation using Sodium Iodide necessitates a single washing of the sediment, while sodium chloride requires minimum of three. Conversely, Sodium Iodide reacts with cellulose filters, which result to black and confusing visual identification. Sodium Iodide is able to recover oleophobic fibers (92.4 percent). When an elutriation column is used, Sodium Iodide can be reused for about 10 cycles through evaporation and rising steps, having comparable costs to sodium chloride. Therefore, using sodium Iodide is highly recommended, some of its advantages include; (1). It can be recycled, (2). It is safe to use in our environment, although sodium iodide cannot be used with a cellulose filter. The Sediment-MP Isolation, a device consist of two tubes connected by a valve which allows separation of both supernatant and sediment, has an efficiency of 94.3 percent when used with zinc chloride (1.5 g $cm^3$) (Vollertsen and Hansen, 2017). The device is shown in the supplementary section sin Fig. S4.

In elutriation process, water is injected at the base of a column, which allow separation of buoyant MPs from the settling organic matter and sediment. MPs are collected the column mesh and separated using sodium Iodide. Elutriation has several advantages; it is cheap and very efficient in separating MPs from large volumes of sediments. Thus reducing sample volume that undergoes density separation. Conversely, elutriation takes at minimum of 1 h per sample (Sighicelli et al., 2018).

### 2.3. Statistical analysis

All data were statistically analysed using Microsoft excel 2016. Normality and homogeneity of variances were calculated. One-way analyses of variance (ANOVA) was used to determine the variation between microplastic quantities in different sample site. For example, the microplastic abundance in surface water and sediments. Student's-T Test ($p < 0.05$) level of significance was used to analysed the difference between two groups (sediments and surface water for both raining and dry seasons). Beljanski et al. (2016) test was used in determining the significant differences that occur in multiples samples ($N \geq 3$) for the microplastic quantities (the number of filtered microplastic quantities recovered).

### 2.4. Observation and identification of microplastics

Microplastics on the filters were cautiously observed for the two seasons and identified under a stereo light microscope (Berwick SM-904, Berlin, Germany). MP can be identified from other materials based on the outer morphological and physical appearances of plastic debris as explained by Harrison et al., 2012. MPs sizes, shapes and colours on the filters were verified following Su et al. (2016). Based to their morphologies, identified microplastics was categorised into seven types, which are fibres, pellet, fragment, bead, film and flake. The colours were recorded based on dominant surface colour. A sub-sample of identified microplastics was selected at random from various samples and confirmed the composition by micro-FTIR (Nicollet iN 10.0, Thermo Fisher, United states) attached with MCT detector. The infrared spectrum in the range of 4000–400 per cm was collected four times on each identified particle to achieve better spectra. The spectra obtained were compared with the standard FTIR spectrum databases using OMNIC software (Thermo Fisher, United States). The microplastic composition was ascertained, while matching degree with standard spectrum N 80%.

## 3. Result and discussion

Microplastic occur in all water and sediments samples for dry and raining seasons for abundance, shape; colour and size.

### 3.1. Microplastics abundance

MPs were identified in all sediments and water samples from 10 sampling sites, with abundance ranged from 1004 to 8329 items·$m^{-3}$ for dry season and 201–8369 items·$m^{-3}$ for raining season respectively as illustrated in Figs. S5,S6,S7 and S8. However, the most contaminated sites for both seasons in surface water and sediments are shown in figure S, as follows: for dry season surface water/sediment are sites (s1/s10) and for raining season the most contaminated sites are (s7/s4) respectively. During the dry season, sites (s1 and s10) could be as a result of lack of proper sewage in the region and indiscriminate dumping of refuse around the site couple with the farming and fishing activities. In addition, the site is the hob where flying boats and canoes are used in transporting goods from one village to another. In sediment samples for dry season, MP abundance varied from 347 to 4031 items·kg − 1. This may occur as a result of the microplastic pollution of the sediments which might be superimposed by hydrodynamic effects in the area, wind direction and source loading.

For raining season, majority of the water coming from the ocean flows through the site as well as yenagoa and other surrounding cities, thereby depositing MPs in the site. Sites (s7 and s4) site is few kilometres close to a bottling company, wires and Cables Company and a plastic company, which may possibly discharge MPs into the site during the raining season via erosion. In addition, site s7 is located at the confluences of different tributaries. In raining season the sediments gives a range of 507–7593 items·$kg^{-1}$ respectively. The high

**Table 2**
MPs occurrence for some selected locations around the continent.

| Study area | samples | Size (mm) | Abundance | Main types | Reference |
|---|---|---|---|---|---|
| Asia | | | | | |
| Taihu lake, China | Lake sediment | 0.005–5.0 | 11.0–234.6 items/kg | CP,PA,PE,PET, PP | Carr et al. (2016). |
| Lake Hovsgol | Surface water | > 0.333 | Maximum: 44,435 | Not identified | |
| Taihu lake, China | Surface water | 0.333–5.0 | $0.01\times 10^{-6} - 6.8 \times 10^{6}$ | CP,PA,PET, PP | Su et al., 2016 |
| Three gorges reservoir, China | Surface water | 0.112–5.0 | Max. $13.0 \times 10^{6}$ | PE, PP, PS | Bayo et al., 2016 |
| Three urban estuaries, China | Surface water | > 0.5 | 100–4100 items/$m^3$ | PP, PVC, PTFE, PE | Wang et al. (2017). |
| **Europe** | | | | | |
| Swiss Lakes, Switzerland. | Surface water | 0.3–5.0 | 91,000 | PE, PP, PS, PVC | Zhao et al. (2014) |
| Swiss Lakes, Switzerland | | | | PE, PP, PS, PVC | Zhao et al. (2014) |
| Lake Garda, Italy and | Beach sediment water | < 5.0 | 108–1108 | PE, PP, PS, PVC, PA | Zhao et al. (2014) |
| Lake Chiusi, Italy | Beach sediment water | 0.3–5.0 | 4.08 items/$m^3$, 1700 $\times 10^{6} - 2462 \times 10^{6}$ | Not identified. | Zhao et al. (2014) |
| Rhine - Main area, Germany | Beach sediment water | < 5.0 | 220–3700 item/kg | PA,PE,PP,PS | Beljanski et al., 2016 |
| Seine River, France | Surface water | | 0.8–5.1% of total debris by weight | PP,PET,PP,PS, PVC | Hernandez et al. (2017) |
| Tamar Estuary, England | Surface water | 0.3–5.0 | Mean: 0.028/$m^3$ | PP,PP,PS, PVC | Cole (2016) |
| **North America** | | | | | |
| Lake superior | Surface water | > 0.355 | Mean: 5390.8 Range: 6875–12,645 | Not identified | Ziajahromi et al. (2017) |
| Lake Huron | Surface water | > 0.355 | Mean: 2779.4 | Not identified | Rodrigues et al. (2018) |
| Lake Erie | Surface water | > 0.355 | Mean: 105,502 Range: 4686–466,305 | Not identified | Cole (2016) |
| Lake Erie | Beach sediment | Not specified | Mean: $1.537 \times 10^{6}$ Range: $0.36 \times 10^{6} - 3.7 \times 10^{6}$ | PP, PE | Rodrigues et al. (2018) |
| Lake St. Clair | Beach sediment | Not specified | Mean: $1.726 \times 10^{6}$ Range: $0.18 \times 10^{6} - 8.38 \times 10^{6}$ | PP, PE | Hernandez et al. (2017) |
| St. Lawrence River, Canada | River sediment | > 0.5 | Mean: $1.726 \times 10^{6}$ Range: $0–136{,}920 \times 10^{6}$ | PE | Hernandez et al. (2017) |
| North shore channel, Chicago, USA | Surface water | > 0.333 | Range: $0.73 \times 10^{6}$ - $6.698 \times 10^{6}$ | Not identified | Hernandez et al. (2017) |
| **Africa** | | | | | |
| Lake Victoria, Mwanza Region of Tanzania | fish | > 0.25 | 20% of fish | PE, PES, PUR, PE/PP. | Ziajahromi et al. (2017) |
| Five urban estuaries of KwaZulu – Natal, South Africa | Surface water | > 0.25 | Range: 2–487.5 item/1000 L | PS | Rodrigues et al. (2018) |
| Five urban estuaries of KwaZulu – Natal, South Africa | River sediment | > 0.02 | Range: 13.7–745.4 item/500 mL | PS | Ziajahromi et al. (2017) |

abundance of sediments in raining season recorded in site s4 may be due to chemical pollution and wind direction. In all, no similarities was recorded in both surface water and sediment for both seasons.

### 3.2. Microplastics colours

Seven colours were observed for MPs items, they include black, yellow, green, red, blue, white, and purple. Red accounted for about 42.4% of the total samples in summary for surface water and 44.1% for sediments as shown in S9 and S10 for dry season. The colour distribution of microplastics were different in each sampling site in S11 and S12 for raining season, at this time the green colour accounted for 61.2% for surface water and 60.2% for sediments respectively, this is an indication that MPs are more predominant in raining season. The water level is predominantly high due to the raining season; therefore, larger debris of microplastics will be present. In addition, other particles that come along with the MPs from the ocean and within the environment, for example, debris, the green algae matter and grasses growing along the bank of the lake could be responsible (Hidalgoruz et al., 2012; Vollertsen and Hansen, 2017).

### 3.3. Microplastic shape distribution

MPs from the OX- BOW Lake, were classified into six types (fibre, beads, fragment, pellet, films and flakes), according to their shapes. All MPs were present in all samples. MPs were identified as fibres, pellets, fragments and films based on their morphological properties. The amounts of fibres, pellet, fragments, films and flakes for surface water and sediments in dry season for both from S13 and S14 were 5.1%, 4.6%, 8.4%, 73.1%, 4.1% and 4.7% respectively. The fraction of beads was significantly more than that of fibres (ANONVA, F = 14.280, p = 0.002), pellet (ANONVA, F = 11.680, p = 0.000), fragments (ANONVA, F = 15.003, p = 0.002), films (ANONVA, F = 11.080, p = 0.002) and flakes (ANONVA, F = 12.080, p = 0.001). Surface water and sediments in raining season for S15 and S16 the proportions of pellets was significant than fibres, fragments, beads, films and flakes in dry season. Fibres has (ANONVA, F = 14.220, p = 0.000), fragments (ANONVA, F = 13.145, p = 0.002), beads, (ANONVA, F = 14.110, p = 0.000), films (ANONVA, F = 13.000, p = 0.001) and flakes (ANONVA, F = 12.880, p = 0.002). The large quantity of beads in surface water was possibly due to the stock of trade by the rural dwellers, which are more into bead making as their cultural heritage, and some of them uses it as a tool in fishing. The plastic company in Yenagoa mostly palletise their plastics, for easy transportation to neighbouring communities and states. The presence of pellets in the sediment could be attributed to it. However, agricultural irrigation, atmospheric deposition and surface runoff are probable sources of pellets MPs in OX BOW Lake. Fragments were dispersed in all water samples and sediments. The cause of fragments may occur from large plastics deposition, for example, mulching film, packing materials, cleaning products and plastic utensils. Film was observed all water samples and sediments, probably from the breakdown of packaging materials, plastic bags and containers. Fragmentation process and residence time in water will affect MP shape. The occurrence of abundant

fibres in the wastewater may result to large quantity of fibres being discharge through household washing machine into a septic tank (most region disposes their sewage through the septic tank, while some are through open drainage, which may not be effective). This occur as a result of high abundance of polymers in the wastewater from manufacturing synthetic clothes. High fibre occurrence could be attributed to the difficulty in differentiating synthetic fibres from natural fibres; some studies also involved the natural fibres during the quantification. Researchers demonstrated that the natural fibres (cotton and linen) could justify for more than a half of fibres in some wastewater samples (Catarino et al., 2016). The microplastic flakes could be mostly found from the erosion of plastic bags and packing products.

### 3.4. Microplastic size distribution

In dry season, the average percentage for surface water and sediments in most microplastic sizes were in the ranges of 0.02–0.5 mm (4.3%) ($p < 0.05$), and 0.51–1 mm (6.7%) ($p < 0.01$), 1–3 mm (74.9%) ($p < 0.05$), 3–5 mm (14.1%) ($p < 0.01$), as shown in S17 and S18. S19 and S20 shows the surface water and sediments in raining season, on average the microplastic sizes were in the range of 0.02–0.5 mm (4.9%) ($p < 0.05$), and 0.51–1 mm (89.1%) ($p < 0.01$), 1–3 mm (4.7%) ($p < 0.05$), 3–5 mm (2.3%) ($p < 0.01$). Nembe has the largest size (0.51–1 mm) compared to other section of the lake. Smaller microplastic in our environment may originate from deep fragmentation of enormous plastic debris. Epie has the largest size (1–3 mm) compared to other section of the lake. Nevertheless, some researchers shows that size distribution of MPs skews towards smaller sizes, as a result of the degradation of larger plastic debris. S21 and S22 shows Images of samples under steriolight for both seasons and S 23 and S24 shows Images of samples under FTIR for both seasons.

Based on the μ-FTIR results for dry season in surface water and sediments, Tables 3 and 4 shows the proportion of Polyethylene terephthalate (PET, 72.6%, 77.4%) was the largest, followed by Plasticised polyvinyl chloride (PVC P, 10.9% 11.3%) respectively with density of 1.38 and 1.35. This could be attributed to the presence of three plastic companies in the region (few kilometres from the lakeside) responsible for producing PET bottles, for soft drinks and water; others could be attributed to the importation of raw material of PET production from other regions. For raining season, in Tables 5 and 6, the results for surface water and sediments, shows that Plasticised polyvinyl chloride (PVC P) has the highest proportion of polymer identified with 81.5 and 83.5% respectively. PVC P are majorly electric cables, the city shares boundary with another City, where electric cables are produced, and its source may emanate from them. The high presence of PVC P in the lake during the raining season occur due to the erosion of water been transported from other neighbouring communities which solely deals with PVC P into the region. There were no traces of HDPE and PMMA. Although in Nigeria, research is yet be carried out on the presence of HDPE and PMMA in other marine sites. Tsang et al. (2016) reported the presence of HDPE in surface water with the concentration of 51–27,909/100 $m^3$ in coaster water Hong Kong. In addition, Yu et al. (2016) showed that 102.9 ± 39.9 Concentration (items/kg) of HDPE is present in beach sediments in Bohai Sea, China. Ballent et al. (2016) reported that 980 dry weight of PMMA is present in lacustrine sediment, Ontario Lake, Canada.

MPs occurrence in some selected locations around the world in inland waters are shown in Table 2. A comparison of data from different regions can be challenging due to the difference in sampling methods used, size ranges investigated, and the reporting units that are employed (Harrison et al., 2012). There is need to adopt universal criteria for sampling and reporting MPs occurrence data to facilitate a comparison. However, the abundance of MPs from different regions differs by magnitude. Even within the same region, the abundance of MPs varies considerably. This uneven distribution pattern can be related to their relatively low density loading rate. Carr et al. (2016) demonstrated that MPs were also found at relatively high concentrations in inland waters from remote areas with limited human activities. This is likely due to a lack of proper waste management measures in those areas. In many Asian countries, high population density and unsound waste management systems lead to a high risk of inland water pollution by MPs as well as many other pollutants (Abrahams et al., 2007).

PETE polytetrafluoroethylene, PUR polyurethane, PVC polyvinyl chloride, PA polyamide, PET polyethylene terephthalate, PA polyamide, PE polyethylene, PS polystyrene, PES, polyester, CP cellophane.

The occurrence and distribution of MP for two seasons (dry and raining) were investigated in OX- Bow Lake Yenagoa, Nigeria for surface water and sediments and the influence factors of their distributions were discussed. MPs were found in water and sediments from all sections. Microplastic was most predominant in water were at confluence positions of tributaries, while the highest MP occurrences in sediments were recorded in sections at upstream areas. Nevertheless, MP pollution was predominant both in water and in sediments. Fishing, farming, irrigation and municipal waste produced by indigenous communities along the lake may result to the MPs accumulation. To address garbage from plastic more efficiently, waste management systems in the community of Yenagoa need improvement. The common colours of MP were red and green for both dry and raining season in surface water sediments. Beads and pellets were most predominant MP shapes in all samples for dry and raining seasons respectively.

## 4. Conclusion

Microplastic occurrence in OX-BOW Lake, Yenagoa, Bayelsa State was investigated for the first time. Microplastic was most predominant in water were at confluence positions of tributaries, while that of sediments were recorded in sites at upstream areas as a result of pollution. MP occurs in all sites, both surface water and sediments. Fishing, farming, irrigation and municipal waste produced by indigenous communities along the lake may result to the MPs accumulation. The common colours of MP were red in surface water and sediments for dry season, and green for raining season both in water and sediments. MP

**Table 3**
The polymer type, source, resin identification code (RIC), density and percentage occurrence in surface water for dry season.

| Plastic | Source | RIC | Density (g/$cm^3$) | % occurrence |
|---|---|---|---|---|
| Polyethylene terephthalate (PET) | Soft drink and water bottle | 1 | 1.38 | 72.6 |
| Polypropylene (PP) | Plastics container | 5 | 0.855–0.946 | 6.3 |
| Polyethylene (PE) | Supermarket bag | 4 | 0.926–0.940 | – |
| Polystyrene (PS) | Plastics fork, coffee cup lid | 6 | 0.96–1.04 | – |
| Plasticised polyvinyl chloride (PVC P) | Electric cables | 3 | 1.1–1.35 | 10.9 |
| Polyamide (PA) | Thread | 7 | 1.13–1.15 | – |
| Low density polyethylene (LDPE) | Face wash | 4 | 0.915–0.925 | 1.2 |
| High density polyethylene (HDPE) | Chewing gum box | 2 | 0.94 to 0.97 | 7.7 |
| Polymethyl methacrylate (PMMA) | Photographic film | 8 | 0.90–0.94 | – |
| Unplasticised polyvinyl chloride (PVC UP) | Window frame | 3 | 1.35–1.45 | – |

**Table 4**
The polymer type, source, resin identification code (RIC), density and percentage occurrence in sediments for dry season.

| Plastics | Source | RIC | Density (g/cm$^3$) | % occurrence |
|---|---|---|---|---|
| Polyethylene terephthalate (PET) | Soft drink and water bottle | 1 | 1.38 | 77.4 |
| Polypropylene (PP) | Plastics container | 5 | 0.855–0.946 | 5.9 |
| Polyethylene (PE) | Supermarket bag | 4 | 0.926–0.940 | 0.7 |
| Polystyrene (PS) | Plastics fork, coffee cup lid | 6 | 0.96–1.04 | – |
| Plasticised polyvinyl chloride (PVC P) | Electric cables | 3 | 1.1–1.35 | 11.3 |
| Polyamide (PA) | Thread | 7 | 1.13–1.15 | 1.2 |
| Low density polyethylene (LDPE) | Face wash | 4 | 0.915–0.925 | 0.5 |
| High density polyethylene (HDPE) | Chewing gum box | 2 | 0.94 to 0.97 | 1.1 |
| Polymethyl methacrylate (PMMA) | Photographic film | 8 | 0.90–0.94 | – |
| Unplasticised polyvinyl chloride (PVC UP) | Window frame | 3 | 1.35–1.45 | – |

**Table 5**
The polymer type, source, resin identification code (RIC), density and percentage occurrence in surface water for raining season.

| Plastics | Source | RIC | Density (g/cm$^3$) | % occurrence |
|---|---|---|---|---|
| Polyethylene terephthalate (PET) | Soft drink and water bottle | 1 | 1.38 | **2.6** |
| Polypropylene (PP) | Plastics container | 5 | 0.855–0.946 | – |
| Polyethylene (PE) | Supermarket bag | 4 | 0.926–0.940 | **0.3** |
| Polystyrene (PS) | Plastics fork, coffee cup lid | 6 | 0.96–1.04 | 0.1 |
| Plasticised polyvinyl chloride (PVC P) | Electric cables | 3 | 1.1–1.35 | 81.5 |
| Polyamide (PA) | Thread | 7 | 1.13–1.15 | 1.7 |
| Low density polyethylene (LDPE) | Face wash | 4 | 0.915–0.925 | 0.9 |
| High density polyethylene (HDPE) | Chewing gum box | 2 | 0.94 to 0.97 | – |
| Polymethyl methacrylate (PMMA) | Photographic film | 8 | 0.90–0.94 | – |
| Unplasticised polyvinyl chloride (PVC UP) | Window frame | 3 | 1.35–1.45 | 3.1 |

**Table 6**
The polymer type, source, resin identification code (RIC), density and percentage occurrence in sediments for raining season. Resin identification code (RIC).

| Plastics | Source | RIC | Density (g/cm$^3$) | % occurrence |
|---|---|---|---|---|
| Polyethylene terephthalate (PET) | Soft drink and water bottle | 1 | 1.38 | 3.4 |
| Polypropylene (PP) | Plastics container | 5 | 0.855–0.946 | 0.1 |
| Polyethylene (PE) | Supermarket bag | 4 | 0.926–0.940 | 2.6 |
| Polystyrene (PS) | Plastics fork, coffee cup lid | 6 | 0.96–1.04 | 0.3 |
| Plasticised polyvinyl chloride (PVC P) | Electric cables | 3 | 1.1–1.35 | 83.9 |
| Polyamide (PA) | Thread | 7 | 1.13–1.15 | – |
| Low density polyethylene (LDPE) | Face wash | 4 | 0.915–0.925 | 4.2 |
| High density polyethylene (HDPE) | Chewing gum box | 2 | 0.94–0.97 | – |
| Polymethyl methacrylate (PMMA) | Photographic film | 8 | 0.90–0.94 | – |
| Unplasticised polyvinyl chloride (PVC UP) | Window frame | 3 | 1.35–1.45 | 5.1 |

shapes and size distribution of quantified using ANOVA. Polyamide (PA) and Polystyrene (PS) traces of MPs were very low in both surface water and sediments for both season. To address plastic pollution, domestic waste management systems in Yenagoa needs improvement. Awareness to the populace on the need for environmental protection is necessary. Polyethylene terephthalate (PET) recorded the highest MP in dry season at an average of 76%, while Plasticised polyvinyl chloride (PVC P) in raining season recorded an average of 82.4% respectively. There were no traces of HDPE and PMMA.

## Credit author

Babalola Aisosa Oni prepared the entire manuscript. Augustine Ayeni, Oluranti Agboola, Tomiwa Oguntade and Oyinlola Obanla did the editing and reviewing of the manuscript only.

## Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

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